UNCLASSIFIED

AD 428145

DEFENSE DOCUMENTATION CENTER

FOR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION, ALEXANDRIA, VIRGINIA

UNCLASSIFIED

N-64-8

UNCLASSIFIED

TECHNICAL MEMORANDUM

U.S. NAVAL APPLIED SCIENCE LABORATORY
NAVAL BASE
BROOKLYN 1, NEW YORK

USNASL-9110-P-1J

REPORT OF INVESTIGATION
OF
CAVITATION EROSION RESISTANCE AND RELATED PROPERTIES OF POTENTIAL HYDROFOIL STRUCTURAL ALLOYS AND COATINGS

SF 013-13-01, Task 0906

Bureau Identification No. 14-906-1

Lab.Project 9300-17, Technical Memorandum #2

30 JAN 1964

MATERIAL SCIENCES DIVISION

APPROVED: D. H. Kallas
D. H. Kallas
Associate Technical Director

U.S. NAVAL APPLIED SCIENCE LABORATORY
NAVAL BASE
BROOKLYN, NEW YORK 11251

Lab.Project 9300-17
Technical Memorandum #2

Ref: (a) H.S. Warkentin and A.E. Hohman, Selection of Materials for Large High Speed Hydrofoils, Presented at IAS and Bureau of Ships Conference, Washington, D.C. 17 Sep 1962
(b) Ivo Fioriti, John Vasta and Alan Starr, Materials for Hydrofoils, SAE Paper 690A, National Aero-Nautical Meeting, 8-11 Apr 1963
(c) H.S. Warkentin and A.E. Hohman, Which Materials for Hydrofoils? Materials in Design Engineering of May 1963, pp. 88-90
(d) Chance-Vought Report No. 2-53/100/2R390 of 15 May 1962
(e) Chance-Vought ltr 2-50000/2L41 of 12 Jan 1962, enclosure (1)
(f) A.E. Hohman, Presentation at Sea Horse Institute, 4 Jun 1963
(g) Chance-Vought Report 2-53100/3R454 of 1 Apr 1963
(h) NAVSHIPYDNYK MATLAB ltr 949:JZL:nt, Lab.Project 4759-14, Progress Report 7 of 18 Apr 1961
(i) J.Z. Lichtman, D.H. Kallas, C.K. Chatten and E.P. Cochran, Jr. Cavitation Erosion of Structural Materials and Coatings Corrosion, Vol. 17 (Oct 1961) 497t-505t
(j) D.H. Kallas, J.Z. Lichtman, and C.K. Chatten, Cavitation Erosion Resistant Coatings, ONR-13 Vol 2, pp 422-442, 1962
(k) NAVAPLSCIENLAB ltr 9370:JZL:nr, Lab.Project 9300-17 of 26 Sep 1963
(l) L.A. Glikman, Corrosion Mechanical Strength of Metals, London, Butterworths, 1962
(m) J.Z. Lichtman, Possible Contributions of Reentrant Flow to Cavitation Erosion, ASME Paper 62-HYD-3
(n) NAVAPLSCIENLAB Lab.Project 9300-17, Technical Memorandum #1 of 18 Sep 1963
(o) NAVAPLSCIENLAB ltr 9370:JZL:nr, Lab.Project 9300-17, of 17 Sep 1963, Cavitation Erosion Damage of Water Brakes
(p) W.C. Leith and A.L. Thompson, Some Corrosion Effects in Accelerated Cavitation Damage, J. Basic Engineering Vol. 82 Ser D (Dec 1960) pp 795-807
(q) M.S. Plesset, The Pulsation Method for Generating Cavitation Damage, J. Basic Engineering (Sep 1963) pp 360-364
(r) NAVAPLSCIENLAB ltr 9370:AR:nr, 9190 of 12 Nov 1963

FIGURES

(1) Photo L - 19527-55 - Cavitation Test Disk Details
(2) Photo L - 19527-20 - Cavitation Erosion Damage of Inconel 718, K Monel and 17-4 PH (1025) alloys
(3) Photo L - 19527-21A- Cavitation Erosion Damage of 17-4 PH (1075) Ti6Al4V, Ti8Al2Cb1Ta, and Berylco 25 alloys
(4) Photo L - 19527-22A- Cavitation Erosion Damage of Cd4MCu, AM 355, Hastelloy C and 4330 alloys
(5) Photo L - 19527-23A- Cavitation Erosion Damage of 4330M alloy and Neoprene and polyurethane coatings on 4330M
(6) Photo L - 19527-53 - Cavitation Erosion Damage of AISI 1016 Disk Alloy
(7) Photo L - 19527-54 - Cavitation Erosion Damage of Rotor of High Speed Water Brake

TABLES

1. This report describes investigations of the cavitation erosion resistance of potential hydrofoil structural alloys and coatings, which were selected by the Chance-Vought Corporation under Bureau of Ships Contract NObs 84593. Relationship between resistance to cavitation erosion and other mechanical and chemical properties of these materials are also discussed. Further studies by NAVAPLSCIENLAB on cavitation erosion of potential hydrofoil materials are being continued under the Hydrofoil Materials Research Program currently underway.

2. Magnetostriction (vibratory) cavitation erosion and other mechanical and chemical properties data obtained in Phase 2 of the Chance-Vought program were reported in references (a) through (g). The cavitation erosion data obtained in NAVAPLSCIENLAB using a rotating disk apparatus are compared with data reported in references (a) through (g). The following conclusions are indicated by the present investigation:

a. The cavitation erosion resistance of the sample alloys tends to increase with increase in hardness, over a broad hardness range. For a relatively narrow range,deviations of erosion resistance with hardness are indicated.

b. The highest cavitation erosion resistance among the metallic materials was shown by the following:

(1) AM 355 - high alloy cast steel
(2) CD4MCU - high alloy cast steel
(3) Inconel 718 - nickel base alloy

The even higher cavitation erosion resistance of elastomeric coatings reported in previous investigations, references (h),(i) and (j) was confirmed by the performance of a 60 mil thick neoprene coating in the tests described herein. However, the adhesion separation of a 20 mil thick neoprene coating during test emphasizes a major prerequisite of such coating systems, namely,adequate adhesive strength to resist the shear flow stresses.

c. The erosion damage pattern in the rotating disk tests, as well as erosion damage in hydraulic machinery, shows a contribution of reentrant flow erosion to the total damage of a material in a cavitating liquid.

d. Low alloy steels show a significant increase in erosion rate in sea water as compared to fresh water indicating a significant contribution of corrosion to the cavitation erosion rate.

e. The level of cavitation erosion intensity of the magnetostriction apparatus as used in the Chance-Vought tests is considerably lower than that of the Laboratory rotating disk apparatus. The low level of erosion intensity in the magnetostriction tests is believed to be due to the low amplitude used in these tests. Those alloys which showed highest static corrosion resistance showed highest erosion resistance in the magnetostriction tests.

3. The information contained herein will be included in the report of cavitation erosion resistance of metals and coatings to be submitted to Hydronautics, Incorporated for inclusion in the U.S. Navy Cavitation Damage Design Handbook, being compiled by this company.

4. Rotating disk tests at NAVAPLSCIENLAB:

a. Test disks and materials. Fifteen mild steel disks having inserts of the test materials located in recesses as shown in Figure 1 were prepared by the Chance Vought Corporation. Duplicates of the test materials were run at linear velocities of 150, 125 and 100 fps. Three disks containing metal inserts were run in fresh water and duplicate disks were run in sea water to obtain information on the significance of the corrosivity of the liquid on cavitation erosion rate. The two disks carrying the elastomeric coating materials were also tested in fresh water. The remaining seven disks were run in sea water. The materials tested, the liquid environments used and times of exposure are given in Figures 2 through 6.

b. Test method. The test disks were run in the rotating disk cavitation erosion apparatus at a shaft speed of 3200 rpm and water pressure of 15 psig. The flow rates and water temperatures at inlet and outlet were as follows.

	Flow rate, gpm.	Inlet; F	Outlet; F
Sea Water	7.8	50	58
Fresh Water	9.5	65	72

The disks were inspected after approximately six hours and 12 hours of total running time. Erosion measurements were made after six hours and 12 hours in the early tests (first three disks) because of adhesion failure of some inserts. Erosion measurements were made in the latter (twelve) tests only after approximately 12 hours. Erosion measurements were made using Hamilton microsyringes calibrated to 0.1 microliter (μl) (5 μl capacity) and 1.0 μl (50 μl capacity). Silicone oil of 50 cs viscosity was used in making the erosion measurements.

5. Magnetostriction cavitation erosion tests. The Chance-Vought magnetostriction tests described by Warkentin and Hohman, reference (a), were carried out at 22,000 cps with a double amplitude of 0.001 inch.

6. Results and Discussion:

a. Rotating disk cavitation erosion tests at NAVAPLSCIENLAB: The nature of the cavitation erosion damage and the cavitation erosion rates of the test materials as determined in the rotating disk tests are given in Figures (2) through (6) and in Table 3. Where adhesion separation of a specimen occurred early in the test, no photo or erosion rate value is shown. Where adhesion separation occurred after a preliminary exposure (approximately 6 hours) and erosion measurement, the preliminary data are given.

(1) Relative erosion resistance. The order of merit of the test materials based on their relative cavitation erosion resistance in sea water is given in Table 4. Rating 1 represents the highest erosion resistant, and rating 14 the lowest among the alloys studied in this group. The 60 mil neoprene coating was the most erosion resistant, showing no damage. This confirmed the Chance-Vought observations and conclusions of other investigations, references (i), (j) and (l), regarding the high cavitation erosion resistance of elastomeric coatings. The 20 mil neoprene coating, however, showed adhesion separation which is a major deficiency as indicated by service experience with erosion resistant coatings, reference (n).

(2) Nature of erosion damage. Most of the metallic test materials, showed concentrated erosion and crevice formation such as described in reference (m). The crevices at the radially inward margins extend into specimen areas which show no erosion damage. In the latter reference, this condition was attributed to cavitation erosion, and subsequent erosion associated with the high velocity reentrant flow at the base of the cavity, adjacent to the meter surface. The present tests confirm this conclusion. The cast stainless alloy Cd4MCu showed only slight crevice formation after 12 hours exposure. The crevice formation and erosion pattern shown in the erosion damage to the 22 inch diameter rotor of a 4000 rpm water brake, Figure (7), described in reference (O), resembles the erosion patterns shown by specimens in the rotating disk tests, Figures(2) through (6).

b. Significance of corrosivity of liquid medium: The limited data of Table 1 show a significant increase in erosion rate in sea water only for the AISI 1016 steel disk material, (0.6 µl/hr). When the cavitation erosion resistance of alloys was high, the significance of the corrosivity of the liquid medium on erosion rate decreased. Thus, the erosion resistance of the AISI 1016 alloy was considerably lower than both 4330 alloys. The 4330 alloy (in the Hastelloy C cladding condition) is also susceptible to corrosion attack as shown by (1) its high jet erosion-corrosion rate, and (2) its low corrosion fatigue resistance. However, its high hardness and tensile strength contribute to a higher cavitation erosion resistance than the AISI 1016 alloy. The other 4330 alloy (in the "coating" condition) shows considerably higher erosion resistance. The number of replicates, average erosion rates and standard deviations for the AISI 1016 disk alloy in fresh and sea water were as follows:

Liquid	Velocity (fps)	No. of replicates	Avg. Erosion rate (µl/hr.)	σ(ul/hr)[1]
Fresh Water	100	6	0.01	0.01
	125	6	0.17	0.11
	150	6	1.70	0.56
Sea Water	100	20	0.11	0.076
	125	20	0.28	0.13
	150	20	2.27	0.46

c. Correlations between cavitation erosion resistance and other porperties. Mechanical, corrosion, and cavitation erosion properties of the test materials as given in the Chanco-Vought reports reference in Tables 2 and 3 are presented in these tables for purposes of comparison with the cavitation erosion data determined by use of the NAVAPLSCIENLAB rotating disk apparatus. These correlations are shown in Figures 8, 9 and 10.

(1) Hardness. Most of the test alloys had Rc values greater than 32. All but the 4330 alloy (in the condition for Hastelloy C cladding) had erosion rates of 0.57 µl per hour or less. These erosion rates by comparison with those of lower strength alloys previously tested in the rotating disk apparatus, references (h) and (i), tend to confirm the conclusions of other investigations, including Glikman, Leith and Thompson, references (i) and (p), that cavitation erosion resistance of metals in general, tends to increase with increase in their hardness.

(2) Tensile properties. Comparisons between the cavitation erosion resistance and the strength properties evaluated show highest erosion resistance (rotating disk) for two alloys having the highest ultimate tensile strength, (Inconel 718 and AM 355). However, the following discrepancies are shown:

(1) σ: standard deviation.

(a) The 17-4 PH (1025) alloy has higher strength properties than the (1075) alloy but shows a higher cavitation erosion and jet erosion rate.

(b) The Ti-8Al-2Cb-1Ta alloy has **lower** strength properties than the Ti-6Al-4V alloy but shows a lower erosion rate in the magnetostriction tests. The rotating disk results show the expected relationship.

(3) Other mechanical properties. No correlation is shown between erosion resistance and elongation, modulus of elasticity or impact strength properties.

d. Magnetostriction test results. The magnetostriction cavitation test results showed correlation with static corrosion data, Figure 9. All alloys showing less than 0.1 mil per year (mpy) static corrosion rate (titanium and nickel alloys) also showed magnetostriction erosion rates less than 1 inch per year (ipy); alloys showing higher static corrosion rates than 0.1 mph also showed magnetostriction erosion rates higher than 1 ipy. The low amplitude of operation of the magnetostriction apparatus, paragraph 4, apparently resulted in a low level of cavitation erosion intensity and accentuated the corrosion resistance of a material to a greater extent than the rotating disk apparatus. Studies by Glikman, Leith and Plesset, references (1), (p) and (q), have shown that the erosion rate decreased with decrease in amplitude, reaching zero at a finite amplitude.

7. Conclusions. The following conclusions are based on the results of the rotating disk cavitation erosion tests of the potential hydrofoil alloys and coating materials, and related data as discussed in paragraph 5 above:

a. Cavitation erosion resistance. The cavitation erosion resistance of the structural alloys tends to increase with increase in hardness, although low hardness, high strength elastomeric coatings may show even higher erosion resistance, as indicated in paragraphs 5.a (1) and 5.c.

b. Adhesive strength. The rotating disk tests, paragraph 5.a.(1), confirm the importance of high adhesive strength as well as erosion resistance of the coating system. This requirement was not isolated in the magnetostriction tests in which the shear stresses on the coating are apparently of a lower order of magnitude.

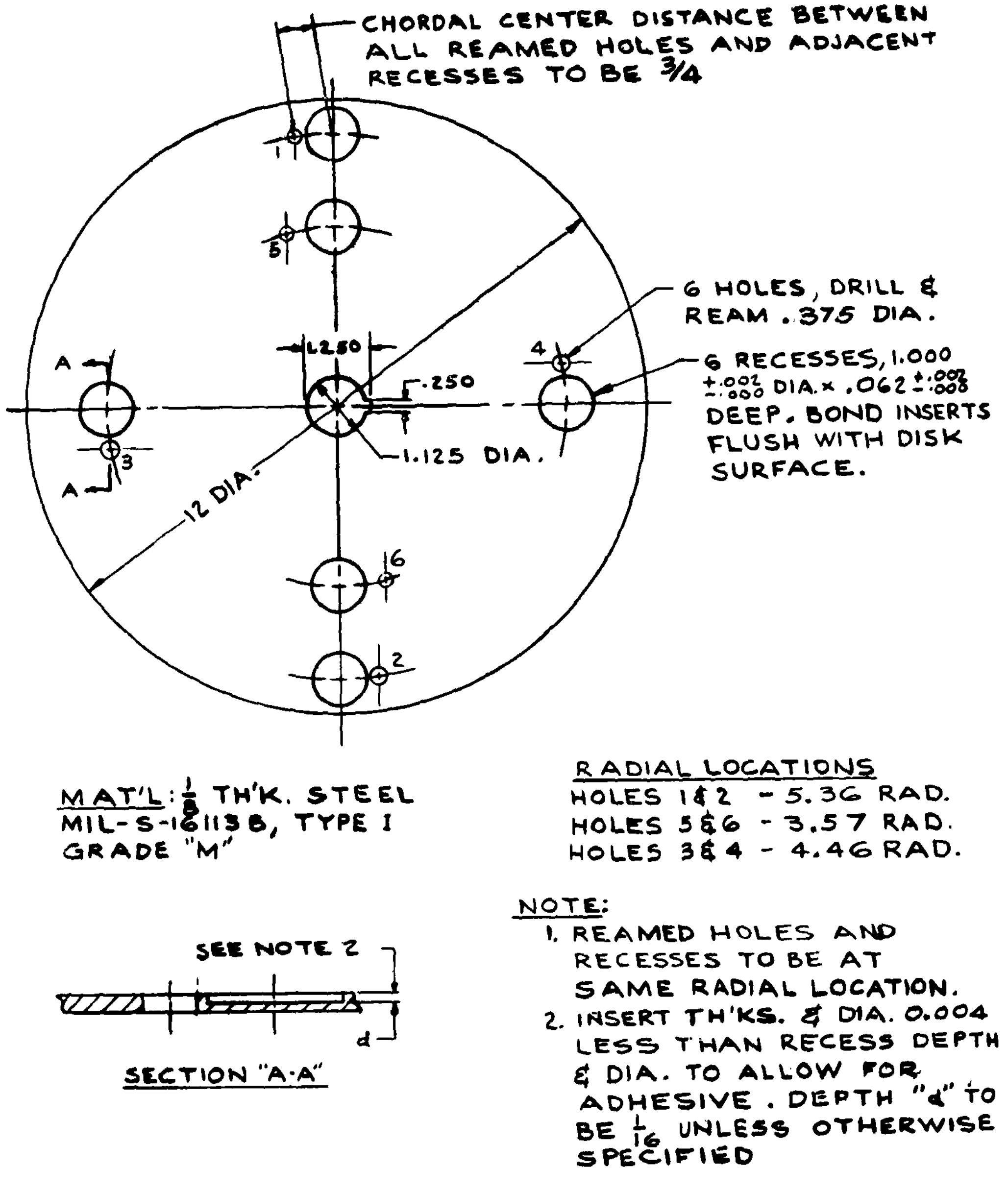
c. The erosion damage patterns shown by the metallic materials in the rotating disk tests, as described in paragraph 5.a.(2), and the erosion damage shown in hydraulic machinery, show a contribution of reentrant flow (high velocity) erosion to the total damage in a cavitating liquid.

d. Corrosivity. The sensitivity of the low alloy steels to corrosion contributes to an increase in the cavitation erosion rate of these alloys in sea water. The significance of this sensitivity tends to decrease with increase in the hardness or erosion resistance, as indicated in paragraph 5.b.

e. The level of cavitation erosion intensity obtained in the Chance-Vought magnetostriction tests is believed to be lower than that obtained in the rotating disk tests because of the low magnetostriction amplitude as indicated in paragraph 5.d. This difference may be confirmed by magnetostriction tests over a range of amplitudes in both fresh and sea water. The differences in levels of erosion intensity would contribute to differences in performance and relative ratings of the metallic materials in the rotating disk and magnetostriction tests, as shown by the data in Table 4.

8. Future Work. Future studies by NAVAPLSCIENLAB on cavitation erosion of potential hydrofoil materials are being continued under the Hydrofoil Materials Research Program currently underway. This program, as outlined in reference (r), covers aspects of hydrofoil materials development in the following areas:

a. Surface protection
b. Structural materials design criteria
c. Hydrofoil assembly systems

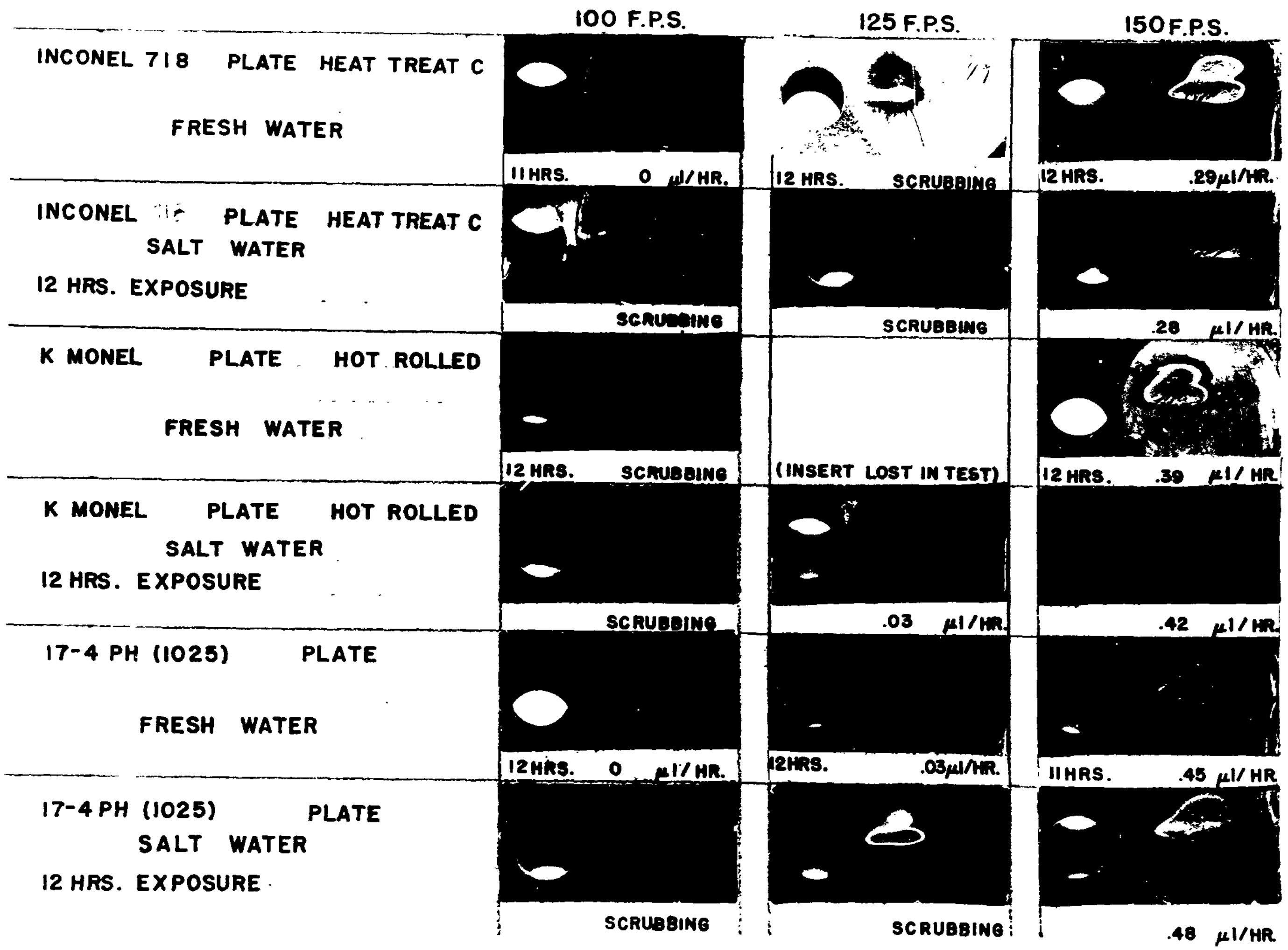


CAVITATION EROSION TEST DISK

APPLIED SCIENCE LABORATORY LAB. PROJECT 9300-17

Figure 1 - Cavitation Test Disk Details

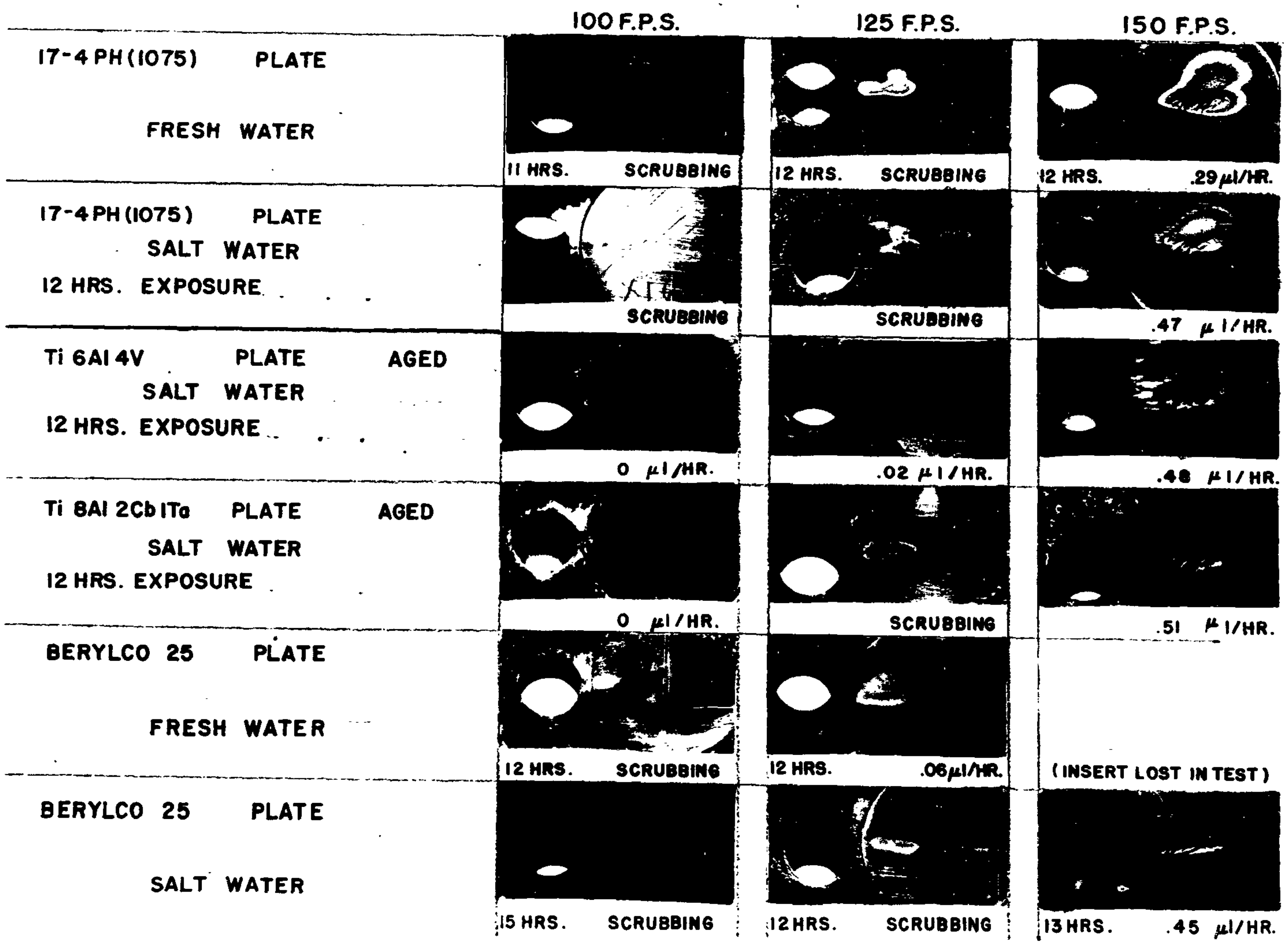
PHOTO L19527-55



APPLIED SCIENCE LABORATORY LAB PROJECT 9300-17

Figure 2 - Cavitation Erosion Damage of Inconel 718, K Monel and 17-4 PH (1025) Alloys

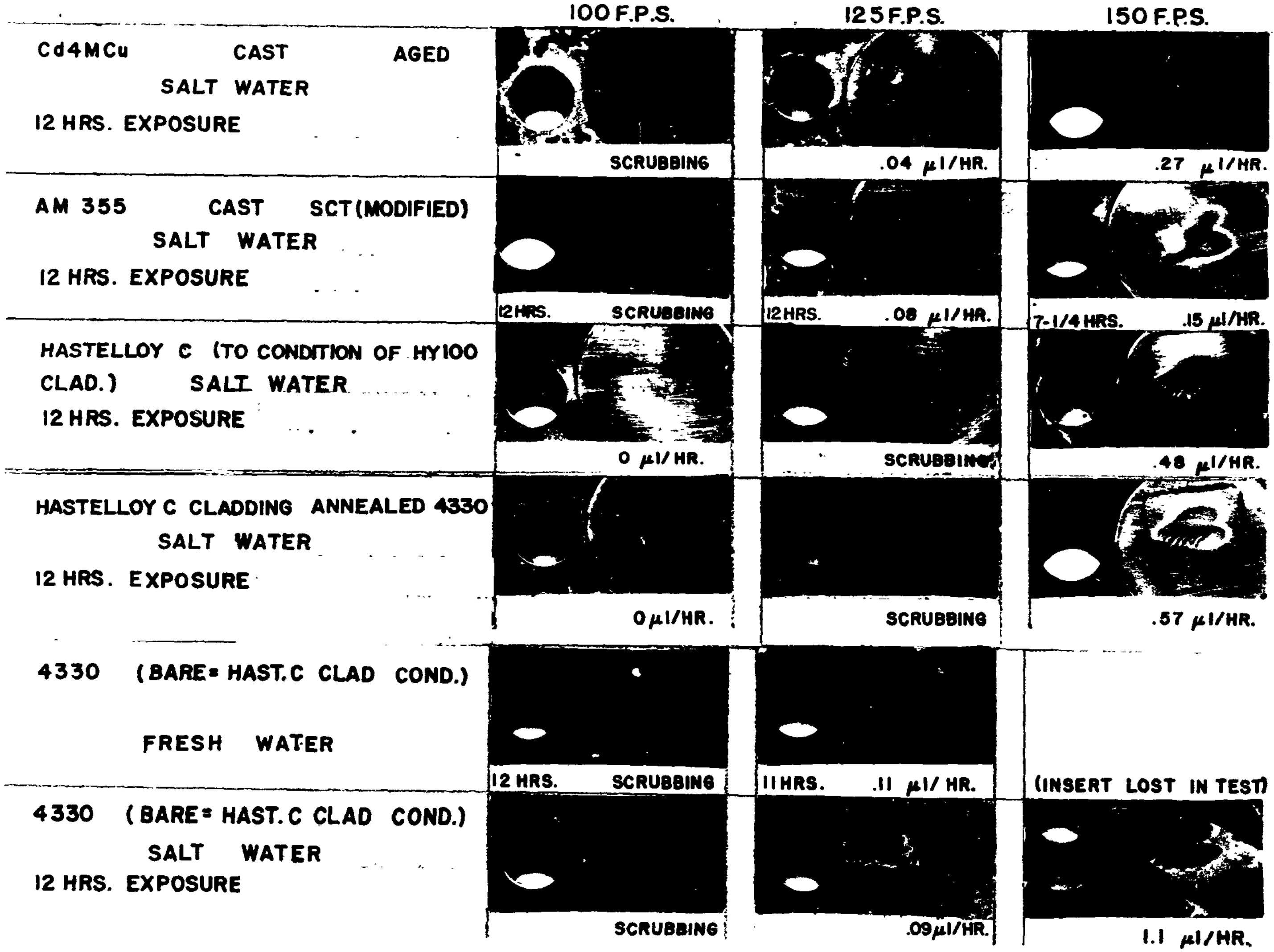
PHOTO L19527-20



APPLIED SCIENCE LABORATORY LAB. PROJECT 9300-17

Figure 3 - Cavitation Erosion Damage of 17-4 PH (1075), Ti6Al4V, Ti8Al2CB 1Ta, and Berylco 25 Alloys

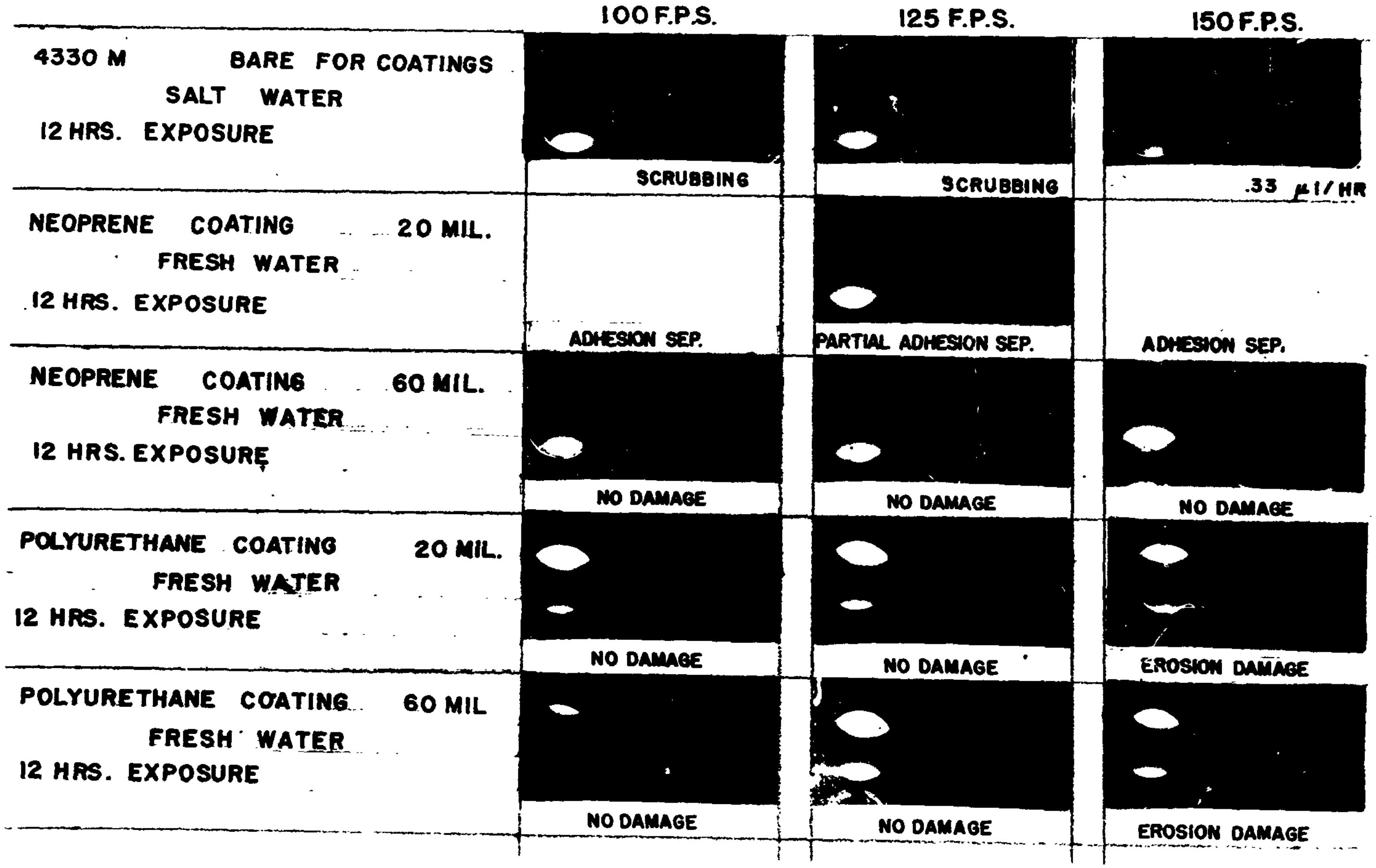
PHOTO L19527-21A



APPLIED SCIENCE LABORATORY LAB. PROJECT 9300-17

Figure 4 - Cavitation Erosion Damage of Cd4MCu, AM 355, Hastelloy C and 4330 Alloys

PHOTO L19527-22A



APPLIED SCIENCE LABORATORY LAB PROJECT 9300-17

Figure 5 - Cavitation Erosion Damage of 4330M Alloys, and Neoprene and Polyurethane Coatings on 4330M

PHOTO L19527-23A

C[illegible]TATION EROSION OF [illegible]. USNASL ROTATING DISK APPARATUS

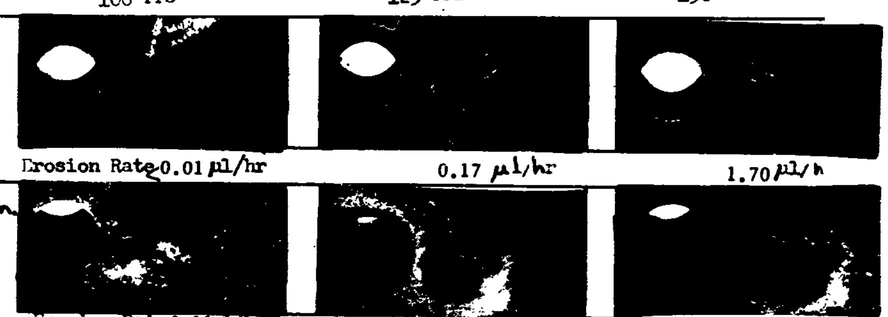
Material Type:

Material: Mild Steel AISI 1016 Thickness __ in.

Liquid: Fresh Water Test Time 12 Hrs.

Material: Mild Steel AISI 1016 Thickness __ in.

Liquid: Sea Water Test Time 12 Hrs



APPLIED SCIENCE LABORATORY LAB. PROJECT 9300-17

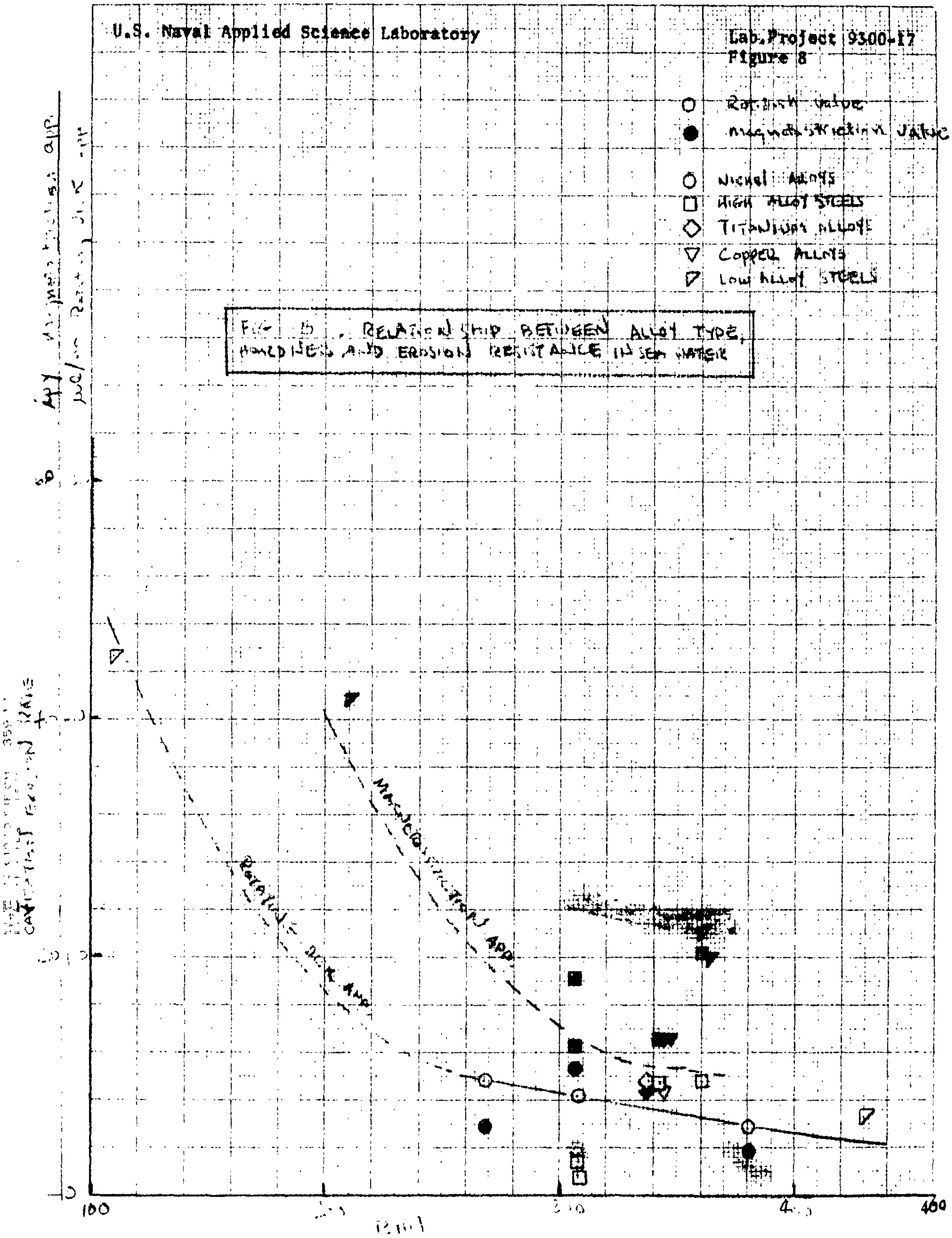
Figure 6 - Cavitation Erosion Damage of AISI 1016 Disk Alloy

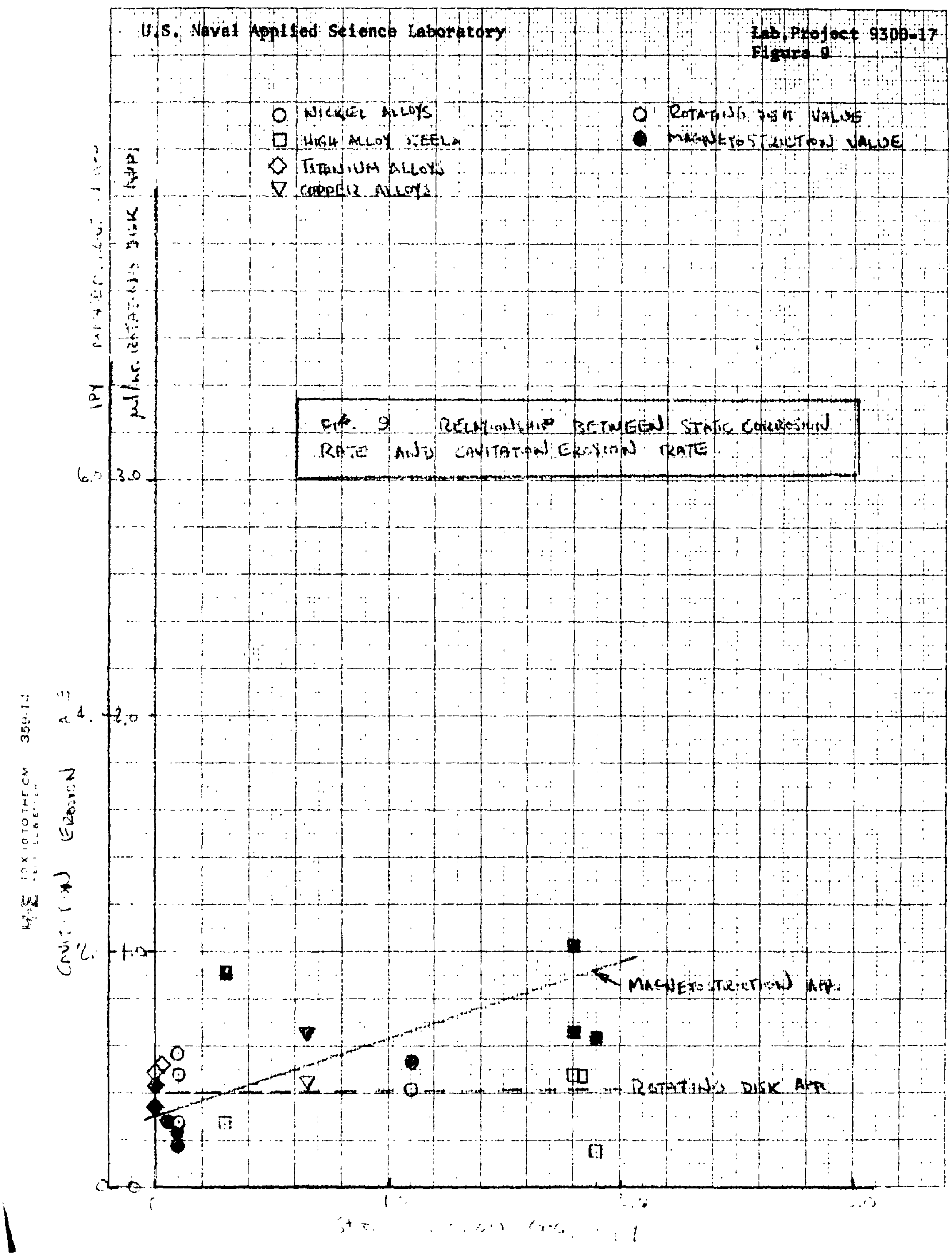
PHOTO L19527-53

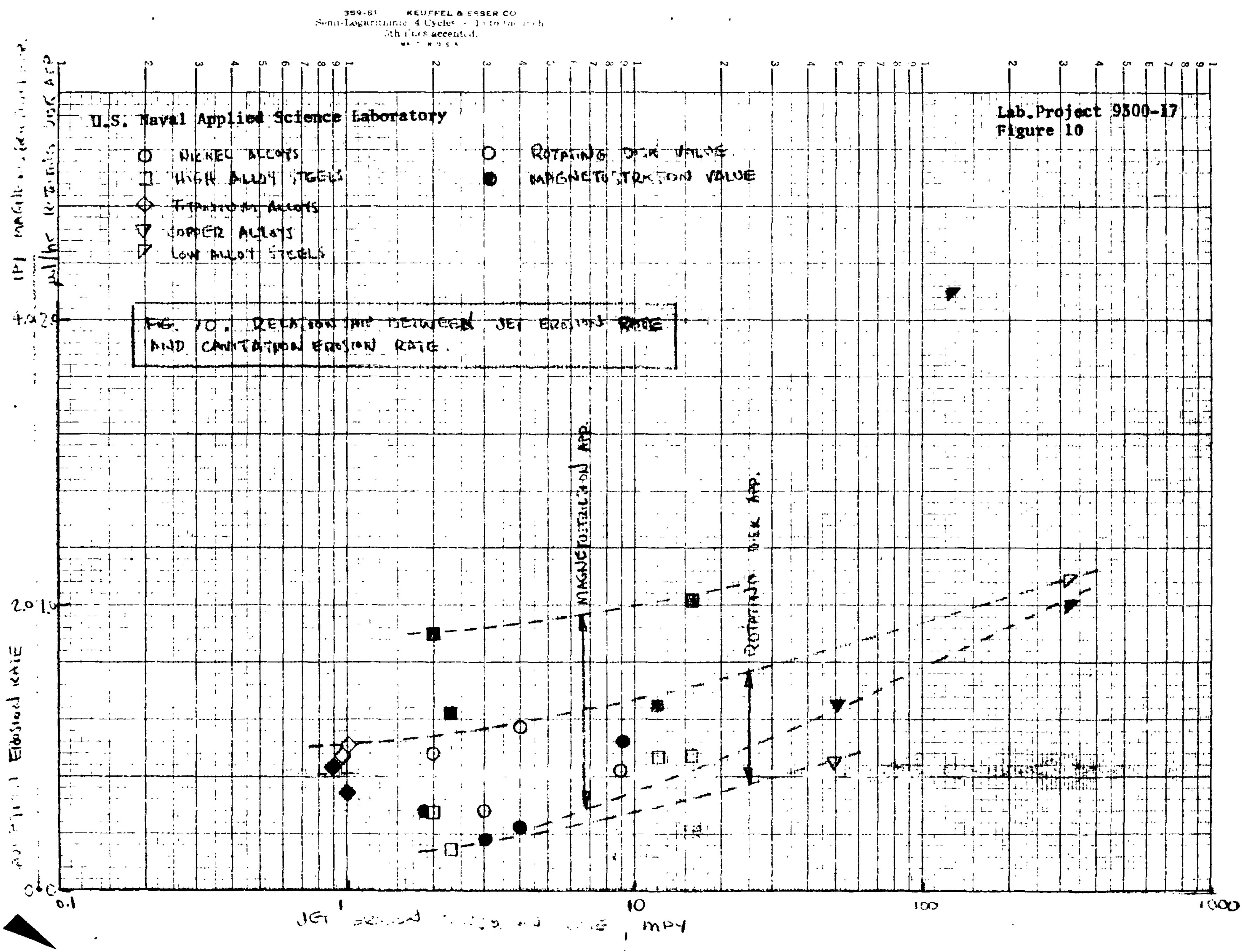
APPLIED SCIENCE LABORATORY LAB. PROJECT 9300-17

Figure 7 - Cavitation Erosion Damage of High Speed Water Brake

PHOTO L19527-54


U.S. Naval Applied Science Laboratory
Lab. Project 9300-17
Figure 8
Rotating value
Magnetostriction value
Nickel Alloys
High Alloy Steels
Titanium Alloys
Copper Alloys
Low Alloy Steels
Fig. 15. Relationship between alloy type, hardness and erosion resistance in sea water
Magnetostriction App.
Rotating disk App.
100
300
400
450


U.S. Naval Applied Science Laboratory
Lab. Project 9300-17
Figure 9
NICKEL ALLOYS
HIGH ALLOY STEELS
TITANIUM ALLOYS
COPPER ALLOYS
ROTATING DISK VALUE
MAGNETOSTRICTION VALUE
FIG. 9 RELATIONSHIP BETWEEN STATIC CORROSION RATE AND CAVITATION EROSION RATE
MAGNETOSTRICTION APP.
ROTATING DISK APP.
3.0
2.0
1.0
0



359-51 KEUFFEL & ESSER CO.
Semi-Logarithmic 4 Cycles
U.S. Naval Applied Science Laboratory
Lab. Project 9300-17
Figure 10
NICKEL ALLOYS
HIGH ALLOY STEELS
TITANIUM ALLOYS
COPPER ALLOYS
LOW ALLOY STEELS
ROTATING DISK VALUE
MAGNETOSTRICTION VALUE
FIG. 10. RELATIONSHIP BETWEEN JET EROSION RATE AND CAVITATION EROSION RATE.
MAGNETOSTRICTION APP.
ROTATING DISK APP.
mil/hr
4.0
2.0
0.0
0.1
1
10
100
1000
MPY

TABLE - 1

EFFECT OF LIQUID CORROSIVITY ON CAVITATION EROSION RATE

	Erosion Rate, µl/hr.					
	Fresh Water Velocity fps			Sea Water Velocity fps.		
Material	100	125	150	100	125	150
Inconel 718 Plate, Heat treat C	0	< 0.01	0.29	<0.01	< 0.01	0.28
K Monel Plate, Hot Rolled	<.01	(1)	.39	< .01	.03	.42
Stainless 17-4 PH 1025 Plate	0	.03	.45	< .01	.01	.48
Stainless 17-4 PH 1075 Plate	< .01	<.01	.29	< .01	.03	.47
Berylco [illegible] Plate	< .01	.06	(1)	< .01	< .01	.45
4330(bare, equal to Hastelloy C clad condition)	<.01	.11	(1)	<.01	.09	1.1
AISI 1016 (12 in. dia. carrier disk)	<.01	.17	1.70	0.11	.28	2.3

(1) Adhesion separation in test.

TABLE 2 - MECHANICAL PROPERTIES OF TEST MATERIALS

Test Material	Fty Ftu PSI 10^3 Ref(d)	% Elongation Ref(e) .050" Thick	.250" Thick	Ref(d)	Mod.of Elast. Psi 10^6 Ref(d)	Hardness Ref (d),(e)	Impact Strength Charpy-V notch, 0°F Ref (a),(b),(g) ENERGY ABSORB Ft.Lb.	BEND ANGLE Avg.	TYPE FRACT (2)
Inconel 718	144-184- 169 197	23.2	20.1	--	29	R_c40 BHN 380	5.3	7	D
K Monel	95- 153- 105 155	22.3	25.0	--	22.5- 26.7	R_c31 BHN 305	11.8	19	D
17-4 PH(1025)	167 177	7.2	12.9	--	29	R_c38 BHN 360	9.7	4	D
17-4 PH(1075)	162 167	7.1	13.6	--	28	R_c36 BHN 342	6.2	7	D
Ti6A14V	142 147	10.7	--	17.0	17	R_c35 BHN 338	15	4	D
Ti8A12Cb1Ta	122 130	--	--	10.0	17.5	--	--	--	--
Berylco 25	125 150	10.8	9.9	12	18.7- 21.5	R_c36 BHN 342	2.0	2	B
CD4MCU	95 135	7.3	11.0	--	29	R_c32 BHN 308	1.3	1	B
AM 355	150-161- 168 186	1.7	9.3	--	29	R_c32 BHN 308	1.2	<2	B

TABLE 2 - MECHANICAL PROPERTIES OF TEST MATERIALS

Test Material	Fty PSI 10^3 Ref(d)	Ftu PSI 10^3 Ref(d)	% Elongation Ref(e) .050" Thick	% Elongation Ref(e) .250" Thick	Ref(d)	Mod. of Elast. PSI 10^6 Ref(d)	Hardness Ref(d),(e)	Impact Strength Charpy-V notch, 0°F Ref (a),(b),(g) ENERGY ABSORB Ft.Lb.	BEND ANGLE Avg.	TYPE FRACT (2)
HY-100 (for cladding)	115	130	--	16.1	16.5	--	R_b95 BHN 210	--	--	--
AISI 4330M (for cladding)	138	142	5.1	13.1	--	--	R_c38 BHN 360	4.7	7	D
AISI 4330 (for cladding)	--	--	--	--	--	--	R_c44(3) BHN 430	--	--	--
Hastelloy C (for cladding on HY-100)	61	126-130	14.4	13.1	29.0	26.5	R_c25 BHN 267	2.2	3	B
Hastelloy C (for cladding on AISI 4330M)	--	--	--	--	--	--	--	1.50	2	B
Mild Steel (12" dia. disks)	--	--	--	--	--	--	R_b65 BHN 110	--	--	--

Notes: (1) Polyurethane coated 4330
(2) D - ductile, - B - brittle
(3) NAVAPLSCIENLAB TEST

TABLE 3 - CORROSION AND CAVITATION EROSION PROPERTIES OF TEST MATERIALS

Test Material	Corrosion Fatigue, Rotating Beam Cycles to failure Ref(b),(f)	Static Corrosion Data, mpy 12 month continuous Ref(g) (3)	JET EROSION - CORROSION RATE IN SEAWATER mpy unwelded Ref(a),(c)	Magnetostriction Cavitation Erosion Data ipy Ref(a),(b),(c),(d),	Rotating Disk Cavitation Erosion Rate, μl/hr at 150 fps Fresh Water	Rotating Disk Cavitation Erosion Rate, μl/hr at 150 fps Sea Water
Inconel 718	>100(10^5) (5)	<0.1 F100	3	0.37	0.29	0.28
K Monel	>100(10^5) (5)	1.1 PC F10-20	9	1.06	0.39	0.42
17-4 PH (H1025)	>100(10^5) (5)	1.8 P F100	16	2.03	0.45	0.48
17-4 PH (H1075)	>100(10^5) (5)	1.8 P F100	12	1.31	0.29	0.47
Ti6Al4V	> 100(10^5 (5)	0 F100	0.9 (6)	0.87	-	0.48
Ti8Al2Cb1Ta	100(10^5)	0 F100	1.0	0.68	-	0.51
Berylco 25	51-58(10^5)	0.5-0.8	50 (6)	1.31	-	0.45
CD4MCU	6.3-15.3(10^5)	0.2-0.4 (4) F100	2 (7)	1.81	-	0.27
AM 355	6.8-11.8(10^5)	1.7-2.1 P F100	2.3 (7)	1.25	-	0.15

TABLE 3 - CORROSION AND CAVITATION EROSION PROPERTIES OF TEST MATERIALS

Test Material	Corrosion Fatigue, Rotating Beam Cycles to failure Ref(b),(f)	Static Corrosion Data mpy 12 month continuous Ref(g) (3)	JET EROSION - CORROSION RATE IN SEAWATER mpy unwelded Ref(a),(c)	Magnetostriction Cavitation Erosion Data impy Ref(a),(b),(c),(d),	Rotating Disk Cavitation Erosion Rate, µl/hr at 150 fps Fresh Water	Rotating Disk Cavitation Erosion Rate, µl/hr at 150 fps Sea Water
HY-100 (for cladding)	--	--	125	4.19	--	--
A1S1 4330M (for cladding)	5.0-5.4(10^5) 50.3-100(10^5) (8)	--	325	2.00	--	1.1
A1S1 4330M (base for coating)	--	--	--	--	--	0.33
Hastelloy C (for cladding on HY -100)	--	<0.1 F100	2	0.56	--	0.48
Hastelloy C (for cladding on A1S1 4330M)	100-132(10^5)	<0.1 F100	4	0.44	--	0.57
Mild Steel (12 in. dia. disks)	--	--	--	--	1.70	2.27
Neoprene	--	--	--	no weight loss	adh.sep (1) no damage	--
Polyurethane	--	--	--	no weight loss	erosion damage (1)(2)	--

NOTES: (1) 20 mil thick
(2) 60 mil thick
(3) F = % fouling, P = Pitting, C = Corrosion
(4) Specimen cracked
(5) USNEES Reports C-3645, 91078B, 910144, 040096
(6) Reference (d)
(7) 10 day exposure
(8) Polyurethane coated 4330M

TABLE - 4

ORDER OF MERIT OF METALLIC MATERIALS ON BASIS OF CAVITATION EROSION RESISTANCE IN SEA WATER

Rating	Magnetostriction Erosion Resistance		NAVAPLSCIENLAB Rotating Disk Apparatus (150 fps)	
1	Inconel 718	(1)	AM 355	
2	Hastelloy C (for cladding on AISI 4330M)		CD4MCu	
3	Hastelloy C (for cladding on HY-100)		Inconel 718	(1)
4	Ti8Al2Cb1Ta		AISI 4330M for cladding	
5	Ti6Al4V		K Monel	(1)
6	K Monel	(1)	Berylco 25	(1)
7	AM 355		17-4 PH (H1075)	(1)
8	Berylco 25	(1)	17-4 PH (H1025)	(1)
9	17-4 PH (H1075)	(1)	Hastelloy C (for cladding on H 100)	
10	CD4MCu		Ti6Al4V	
11	AISI 4330 M (condition not specified)		Ti8Al2Cb1Ta	
12	17-4 PH (H1025)	(1)	Hastelloy C (for cladding of AISI 4330M)	
13	HY 100 (for cladding)		AISI 4330M (bare, for Hastelloy C cladding)	
14			AISI 1016	

(1) Correlation indicated on basis of relative order of merit. Deviations discussed in paragraphs 5d and 6e.